ELIMINATION OF H_2S FROM CHICKEN MANURE BY REACTION WITH H_2O_2 & TITRATING WITH $KMnO_4$

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ABSTRACT

The process of odor removal from the chicken manure (H_2S) can be done in several ways. One of them is the chemical reaction of chicken manure with H_2O_2 and titration with $KMnO_4$. This research was done according to an improvised method with cautious handling of H_2O_2 and chicken manure. The research by using human smell detection used a scale of between 0 until 10 based on the odor strength; the value 0 for no odor and 10 for strangest chicken manure odor. For a volume of 1000mL chicken manure sample comprising 1 kg of improved sample with the addition of 500mL of 11ppm H_2O_2, it was found that there was no more odor of chicken manure and takes 3 hours for reaction between chicken manure and H_2O_2 to get 0 odor of chicken manure. Stiochometric calculation showed that when zero odors were reached in the first experiment 0.0001618 mol H_2O_2 would have reacted with 0.0001618 mol H_2S. Actually by using the human smell detection the results at zero odors may not unrespond with complete removal with H_2S because of the limits of sensitivity of the human nose. That means there may still exits some balance of H_2S in chicken manure after reaction with H_2O_2 by using human detection to zero odors. So, the solution for this problem was using titration with $KMnO_4$ for the balance of H_2S in chicken manure to get to true zero odors or complete removal of H_2S. The detector of H_2S for this titration was the changing color of $KMnO_4$ from dark purple to light pink. That means not changing color of $KMnO_4$ indicates that the odor (H_2S) was fully removed. The result obtained from the second experiment is 0.000451 mol $KMnO_4$ react with 0.0003383 mol H_2S. In calculations one tone of chicken manure contains 17.05g of H_2S. In this research the pH value of the sample was maintained at near neutral condition of pH 7.28.

ABSTRAK

Proses penghilangan bau tahi ayam (H_2S) dapat dilakukan dengan pelbagai cara. Salah satunya ialah dengan tindak balas tahi ayam dengan H_2O_2. Kajian ini dikendalikan mengikut prosedur yang diperbaharui serta berwaspada dengan penggunaan H_2O_2 dan tahi ayam. Keputusan untuk kajian ini dikesan dengan menggunakan deria bau manusia yang berdasarkan kadar bau iaitu diantara 0 sehingga 10.0 tiada bau dan 10 paling tinggi bau tahi ayam. Dan keputusan untuk mendapat 0 bau tahi ayam ialah pada kadar kandungan 500mL (100ppm H_2O_2) dan proses ini memerlukan 3 jam untuk bertindak balas tahi ayam dengan H_2O_2 bagi mendapatkan keputusan 0 bau tahi ayam. Kajian ini dijalankan dengan mengekalkan nilai pH pada keadaan neutral iaitu pada pH 6 sehingga pH 7. Proses penghilangan bau tahi ayam dapat dipercepatkan dalam lingkungan 1 jam dengan menggunakan H_3PO_4 sebagai mangkin dan ini juga dapat mengurangkan penggunaan H_2O_2 dalam kajian tersebut. Tetapi apabila menggunakan H_3PO_4 sebagai mangkin, ia akan menyebabkan proses pencernaan anaerobic tidak akan berlaku kerana pH sampel akan berada di bawah pH 6 iaitu asid dan ini juga akan menyebabkan bekteria di dalam tahi ayam akan mati. Kajian kedua ialah untuk mengetahui berapa banyak kandungan gas CH_4 yang terdapat didalam sampel yang telah ditindak balaskan bersama 500mL (100ppm H_2O_2) dan dikesan dengan menggunakn Micro GC. Tetapi kajian ini dijalankan pada kadar 100g tahi ayam 100mL (100ppm H_2O_2). Dan keputusan yang dikeluarkan oleh Micro GC telah didapati dengan hanya 0.05% gas CH_4. Ini menunjukkan hanya sedikit kandungan gas CH_4 di dalam sampel kerana sampel yang digunakan hanyalah sedikit, ini bermakna, sampel tahi ayam diperlukan dengan banyak untuk menghasilkan kandungan gas CH_4 yang banyak. Proses ini dapat dikomersialkan dan dijual kepada penternak ayam serta menyahut cabaran kerajaan Malaysia iaitu `Zero waste'. Dan proses dapat diperbaiki dengan menggunakan alat pengesan bau berbanding deria bau manusia kerana batasan terhadap deria bau manusia.

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CH_4	-	Gas Methane
CO_2	-	Gas Carbon Dioxide
H_2S	-	Hydrogen Sulphide
NH_3	-	Ammonia
H_2O_2	-	Hydrogen Peroxide
H_3PO_4	-	Phosphoric acid
CH_3NH_2	-	Methylamine
CH_3OH	-	Methanol
Micro GC	-	Micro gas chromatography
V/w	-	Volume over weight
T	-	Temperature
W	-	Weight
%	-	Percent

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Many years, livestock operations such as animal feedlots and poultry have operated with little concern from the public. These operations were very small in nature and rural populations were quite accustomed to the low levels of the odor emitted from these operations. Currently, these operations are getting larger in size and hence producing large amounts of wastes which are causing air, water and soil pollution.

In addition, non agricultural populations have their first or second residence in farming areas and are largely responsible for the air pollution complains. Animal manure contains various complex organic and inorganic compounds as shown in Table 1.1. When handling animal manure, extremely noxious odors arise. The odorous compounds originate during the anaerobic decomposition of animal waste. Anaerobic decomposition of animal waste is a complex biochemical process (Fig. 1.1) that involves a consortium of microorganisms including several groups of acid producing and methane forming bacteria. The acid formers are the primary producer of organic acid, while the methane formers use the acids to produce methane and carbon dioxide.

The decomposition process of organic matter involves the breakdown of protein, carbohydrates and fats into a number of end products. In general, the decomposition process results in the formation of several compounds including alcohols, esters, carbonyls, sulfides, mereaptans, amines, amino acids, organic acids and different gases. The organic acids may include formic, acetic, prop ionic and bacteria. Amino acids may also change to amines by decarboxylation. The breakdown of protein may result in sulfur related amino acids which may produce various sulfides and mercaptans.

The breakdown of fats is an energy releasing process that results in the formation of alcohols and fatty acids which may be broken down to acetic acid. The breakdown of carbohydrates leads to the production of alcohols, Aldehydes, ketons and organic acids. Among the compound of anaerobic decomposition, hydrogen sulfide (H_2S), ammonia (NH_3) and methylamine (CH_3NH_2) are largely responsible for the animal manure odors.

An amines, alcohols, carbohydrates, sulfides, disulfide and mercaptans as volatiles from animal waste and found amine and sulfides to be the most important in terms of the amount of malodorous materials. The formation of organic acids (including butyric, vateric, isobutyric and sovaleric) in liquid chicken manure when the pH was below 8.

Table 1.1: Compounds found in animal manure

Protein	B-lactoglobuline, σ-lactoalbumin, Immunoglobuline, Protosses, Peptones, Poly peptides, Peptides, Enzymes, Amino acids, Arganine, Cysteine, Histidine, Isoleucine, Leucine, Lysine, Methionine, Phenylalanine, Threonine, Tryptophan, Tyrosine & Valine
Non-Protien-N	Ammonia, Urea, Creatinine, Creatine, Uric Acid &-Amine Phosphoethanolamine, ß- Phosphoglyceroethanolamine, Phynyleacetylglutamine, Hippuric acid, Ortic acid & Indican
Fats	Triglycerides, Diglycerides, Monoglycerides, Ketoacid glycerides,

	Ketonogenic glycerides, Lactonogenic glycerides, Nevtrm plasmatorens, Phospholipids, Sphinolipids, Sterols, Squalene, Caretonides, Vitemins (A, D, E, K), Fatty acids, Butric, Caproic, Coprylic, Capric, Lauric, Myristic, Myristoleic, Pentadelanol, Pelmitic, Palmitoleic, Marganl, Stearic, Oleic, Linoteic & Linoleni
Carbohydrates	Cellulose, Hemicellulose, Lignin & Sugars
Minerals	Ca, P, S, Zn, Fe, Cu, K, Na, Cl, Mg, F, I, Mo, Mn & Co
Others	Waxes, Hydrocarbons, Oils & Plastics

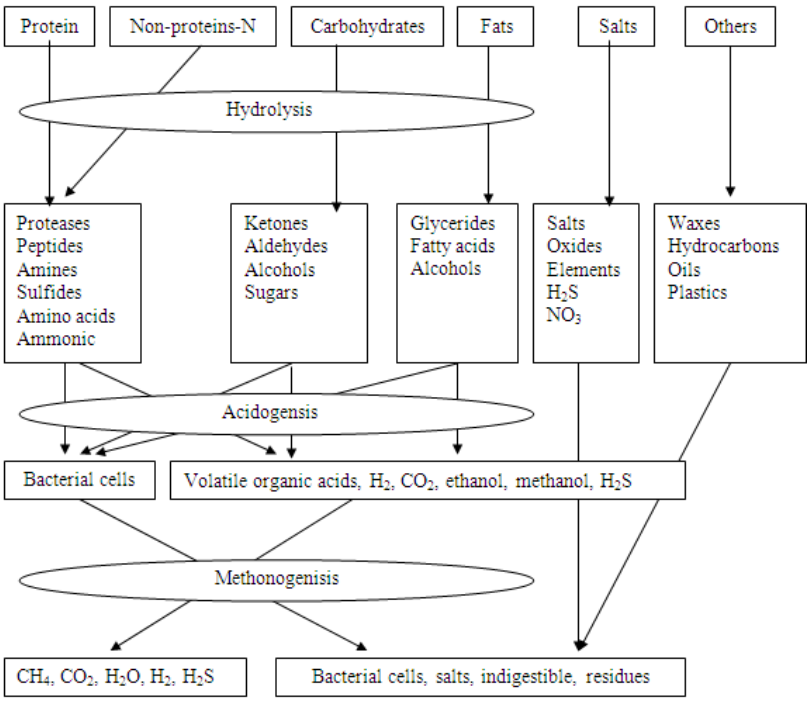

Figure 1.1: Anaerobic decomposition of animal waste

1.2 Background of Study

In this era of globalization in our country. There are some poultry farmers, that story of manure outside for long periods of time is a problem. Every second of the day and night, animals are producing waste products inside their bodies. If those waste products are not removed from the body, the animal may become ill or die. One of the most dangerous of all such waste products is the chemical resulting from the normal breakdown of amino acids (which make up protein) and nucleic acids (of which our genetic material is composed). The main waste product formed during this decomposition is ammonia, NH_3, which is toxic (poisonous)

In mammals such as us humans, our waste ammonia is combined with carbon dioxide, CO_2, and converted into urea, $CO(NH_3)_2$, which is less toxic than ammonia and which dissolves very easily in water. Our bodies dissolve their urea in water, making urine. In other words, when we go pee, basically what we're doing is getting rid of our urea. If we didn't, that urea would build up in our systems and poison us.

Unfortunately, urinating is fairly wasteful of water. Reptiles and birds have developed a different, less water wasting process for dealing with their bodies' ammonia. Instead of converting their ammonia to urea, they mostly convert it to uric acid, $C_5H_4N_3O_3$, which is excreted as a white paste or even a dry, white powder.

It seems that birds and reptiles have developed an ammonia-disposal system that in many ways is better than our mammalian system. If our bodies could convert our ammonia to pasty uric acid instead of urea, we wouldn't have to drink nearly as much water, nor would we have to go pee nearly as often.

But chicken manure is the best as far as sheer nutrients go. It's rich in nitrogen; an application of chicken manure will grow some of the best corn you can imagine. However, chicken manure is what’s known as’ hot’ manure; it will burn plants, and cannot be applied directly to the soil. In order to use it, let it compost for at least three months (six months to a year is better) in an out-of-the-way corner of the garden, then apply it sparingly to your unplanted beds and wait at least two

weeks and one good rain before planting in it. Or, mix it with dry matter, such as leaf mold or sawdust, to cut down on the heat. (Unfortunately, this also dilutes the nutrients. But chicken manure diluted this way makes an excellent organic fertilizer because it can be applied directly to the beds, left two weeks and one good rain, and then planted.

Nowadays in Malaysia wastes generated from the chicken farm are keeping increasing as a result of rapid growth of chicken farm industry. Thus, the application of chicken farm wastes as sources of nutrients for the agricultural production has become an important area of research. Usually, chicken farm wastes such as chicken manures were used directly as an organic fertilizer for crops farming. Direct application of chicken manure into agricultural soil may cause environmental problems such as the foul odor generated, and it may become the breeding ground of pests such as flies. The biological transformation of chicken manure via composting technique has its disadvantage because the process may take several weeks to complete. Chicken manure contains rich plant nutrients that are vital for their growth including nitrogen, phosphorus, and potassium.

In addition to supply of nutrients, the application of chicken farm waste also improves the chemical, physical and biological properties of soil. Therefore, transformation of chicken manure into environmental friendly and easy to handle organic fertilizer is necessary. In this work, chicken manure is transformed into organic fertilizer via chemical mineralization. The mineralization technique was chosen due to its ability to produce mineralized product at very short period.

1.3 Problem Statement

Over 19.5 million tons of chicken and turkey manure produced each year by the industry is no simple task, but a government poultry nutritionist is looking at ways to more carefully balance chicken diets and reduce waste.

The options for manure use are many, but the more practical ones are fuel, feed and fertilizer. Chicken manure can be burned, producing one third the fuel value of coal, or converted to methane in biomass converts. Chicken manure can also be used to feed ruminant animals, such as cattle, that can extract unused nutrients. However, the most common use for chicken manure today is as a fertilizer for agricultural fields.

Excess nutrients in fertilizer are a source of non point source pollution targeted by environmental initiatives like the Chesapeake Bay Pollution Program. The two components of chicken manure that cause the most concern for runoff are nitrogen and phosphorous, but both elements are necessary for good bird health, egg lying and weight gain.

Farmers can control the nitrogen content of manure by using better feed formulation, lower protein diets, and feed additives. In many cases, these approaches save money as well as control the nitrogen output of the birds. Modern breeds of lying and meat birds are more efficient than older varieties. By looking at available rather than total protein, farmers can lower the protein content of feeds and reduce the amounts of nitrogen in manure. Synthetic amino acids are also cost effective and reduce nitrogen waste.

Controlling excess phosphorus centers around supplying phosphorus in a form the birds can use. Feeds such as corn and sorghum contain only 19 to 22 percent bio-available phosphorus with the rest in a chemical form difficult for the birds to digest. The phosphorus in meat or fish meal is 81 to 100 percent bio-available so birds require less phosphorus in their feed thereby reducing the amount of phosphorus in the manure.

Reducing the nitrogen and phosphorus in feeds, in many cases, decreases the cost of the feed. Lowering the nitrogen and phosphorus levels in the manure can also reduce disposal costs for the enormous amounts of chicken manure produced by the poultry industry each year.

1.4. **Research Objectives**

The objectives of this research are to determine how much of the parameters H_2O_2 and $KMnO_4$ quantity to remove the H_2S (odorless) of the chicken manure and how much H_2S was fully removed from the one tone of the chicken manure when process will be done.

1.5 Research Scope of Study

Regarding this particular research, there are several scopes that need to be fulfilling to ensure that research will achieve the objective that had been set.

First scope of this research is to study about how the hydrogen sulfide can remove from the chicken manure when react with hydrogen peroxide and potassium permanganate. Secondly is to analyze how much the hydrogen peroxide and potassium permanganate react with the hydrogen sulfide when hydrogen sulfide is fully removed from the chicken manure. And the last one is to study how the safety precautions are required when doing that research by using hydrogen peroxide and potassium permanganate react with hydrogen sulfide.

This research will focus at the second scope of that experiment. The second scope has the parameters to define. These parameters is more important thing when want to do the experiment of the research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Chicken Manure

The chicken manure contained aerobic heterotrophs, total fungi and crude oil degrading bacteria. The crude oil degraders were identified as species of *Micrococcus, Bacillus, Pseudomonas, Enterobacter, Proteus, Klebsiella, Aspergillus, Rhizopus,* and *Penicillium*. *Pseudomonas aeruginosa* CDB-06 and species of *Bacillus* CDB-08 and *Penicillium* CDF-10 degraded the crude oil at exceedingly high rates. *Pseuedomonas aeruginosa* CDB-06 degraded 65.5 percent of the crude oil after 16 days, while *Bacillus* sp. CDB-08 and *Penicillium* sp. CDF-10 degraded 65.3 percent, and 53.3 percent, respectively of the crude oil over the same period.

The chicken manure also had a pH 7.3, 18.5 percent moisture content, 2.3 percent total nitrogen, and 0.5 percent available phosphorus. Addition of oil polluted soil 10 percent (v/w) pollution level with chicken manure enhanced degradation of the crude oil in the soil. 68.2 percent of the crude oil was degraded in the soil amended with chicken manure, whereas only 50.7 percent of the crude oil was degraded in the un-amended soil after 16 days. The amendment raised the acidic reaction (pH 5.7) of the oil-polluted soil to alkaline (pH 7.2) within 16 days. Chicken manure could, therefore be used in an integrated oil pollution abatement program.

For other way chicken manure is cyclic use of chicken manure incinerated ash as a phosphorus source for feed to chicken? The possibility of utilizing the phosphorus contained in chicken manure incinerated ash as a phosphorus source for

feed to chicken and pig by circulation. It was proven that even if chicken manure incinerated ash was mixed with the feed for broilers and laying hens, the growth performance of broilers and the layer performance of laying hens were not lowered, which showed the possibility of recycling use as a phosphorus source in the feed for chickens.

The effective utilization of chicken manure, although incineration processing using combustion heat has advanced, combustion ash has not been effectively utilized. The fertilizer effects using spinach and tomato as subjects. Chicken manure combustion ash has strong alkalinity such as pH between 11.5 and 13.5 also contains high content of potassium, phosphate and calcium as well as trace elements of iron, manganese, boron and silicate. It is necessary to use the ash by combining with nitrogen fertilizer. Since it does not contain nitrogen component. In a cultivation test, good results were obtained by jointly using CDU, ammonium sulfate, or LP30 as a nitrogen source. The effectiveness of chicken manure combustion ash especially as a PK fertilizer has been done.

Fresh chicken manure may contain disease organisms that could contaminate root crops (carrots, radishes, beets) and leaves (lettuce, spinach), so DO NOT spread un-composted manure on the soil in your vegetable garden. The following “Safety Tips” are summarized.

- Apply only aged or composted manure to your soil.
- Always wear gloves when handling livestock manure.
- Thoroughly wash raw vegetables before eating.
- Do not use cat or dog manure in compost piles.
- People who are susceptible to food borne illnesses should avoid eating uncooked vegetables from manure gardens. Those who face risks from food borne illness include pregnant women, very young children, and persons with cancer, kidney failure, liver disease, diabetes or AIDS.

2.2 How Can Hydrogen Peroxide Remove Hydrogen Sulfide & Sulfur Dioxide From Wastes?

Would hydrogen sulfide and sulfur dioxide both be oxidized by hydrogen peroxide? (If the gases were bubbled through a solution of hydrogen peroxide). Would the result be an acidic solution because of sulfuric acid formation?

Hydrogen sulfide and sulfur dioxide are waste products of several manufacturing processes, and reaction with peroxide is one fairly cost-effective method of removing them from industrial wastes.

The sulfur in hydrogen sulfide (H_2S) is in the -2 state. In a neutral solution, hydrogen peroxide will oxidize hydrogen sulfide to elemental sulfur via the following reaction:

$$8\ H_2S(g) + 8\ H_2O_2(aq) = S_8(s) + 16\ H_2O(l) \qquad (2.2.1)$$

No acid is produced. The reaction takes a while, so if you're bubbling the hydrogen sulfide through the peroxide solution, you need to recycle the gas stream through the peroxide solution. Metal ions catalyze the reaction.

In alkaline solution, you get a completely different reaction. The hydrogen sulfide is present as sulfide ion, and you'll get sulfate after oxidation:

$$S^{2-}(aq) + 4\ H_2O_2\ (aq) = SO_4^{2-}\ (aq) + 4\ H_2O(l) \qquad (2.2.2)$$

The reaction is exothermic and much more rapid than the neutral pH reaction above, but again, no acid is produced.

Acid is produced when SO_2 is bubbled through a hydrogen peroxide solution, though. First the SO_2 dissolves and reacts with water to form sulfurous acid:

$$SO_2(g) + H_2O(l) = H_2SO_3 \quad (2.2.3)$$

The sulfurous acid is then oxidized to sulfuric acid by the peroxide:

$$H_2SO_3(aq) + H_2O_2(aq) = H_2SO_4(aq) + H_2O(l) \quad (2.2.4)$$

2.3 Hydrogen Peroxide (H_2O_2)

Hydrogen peroxide (H_2O_2) is a very pale blue liquid, slightly more viscous than water that appears colorless in dilute solution. It has strong oxidizing properties, and is a powerful bleaching agent. It is used as a disinfectant, antiseptic, oxidizer, and in rocketry as a propellant. The oxidizing capacity of hydrogen peroxide is so strong that it is considered a highly reactive oxygen species.

Hydrogen peroxide is naturally produced in organisms as a by-product of oxidative metabolism. Nearly all living things (specifically, all obligate and facultative aerobes) possess enzymes known as peroxides, which harmlessly and catalytically decompose low concentrations of hydrogen peroxide to water and oxygen.

2.3.1 Physical Properties of Hydrogen Peroxide Solutions

Aqueous hydrogen peroxide solutions have specific properties that are different from those of the pure chemical due to hydrogen bonding between water and hydrogen peroxide molecules. Specifically, hydrogen peroxide and water form a eutectic mixture, exhibiting freezing-point depression. While pure water melts and freezes at approximately 273K, and pure hydrogen peroxide just 0.4K below that, a 50% (by volume) solution melts and freezes at 221 K.

2.3.2 Industrial Applications Uses

About 50% of the world's production of hydrogen peroxide in 1994 was used for pulp- and paper-bleaching. Other bleaching applications are becoming more important as hydrogen peroxide is seen as an environmentally benign alternative to chlorine-based bleaches.

Other major industrial applications for hydrogen peroxide include the manufacture of sodium per carbonate and sodium per borate, used as mild bleaches in laundry detergents. It is used in the production of certain organic peroxides such as dibenzoyl peroxide, used in polymerizations and other chemical processes. Hydrogen peroxide is also used in the production of epoxides such as propylene oxide. Reaction with carboxylic acids produces a corresponding peroxy acid. Per acetic acid and meta-chloroperoxybenzoic acid (commonly abbreviated mCPBA) are prepared from acetic acid and *meta*-chlorobenzoic acid, respectively. The latter is commonly reacted with alkenes to give the corresponding epoxide.

In the PCB manufacturing process, hydrogen peroxide mixed with sulfuric acid was used as the micro etch chemical for copper surface roughening preparation.A combination of a powdered precious metal-based catalyst, hydrogen peroxide, methanol and water can produce superheated steam in one to two seconds, releasing only CO_2 and high-temperature steam for a variety of purposes.

Recently, there has been increased use of vaporized hydrogen peroxide in the validation and bio-decontamination of half-suit and glove-port isolators in pharmaceutical production.

Nuclear pressurized water reactors (PWRs) use hydrogen peroxide during the plant shutdown to force the oxidation and dissolution of activated corrosion products deposited on the fuel. The corrosion products are then removed with the cleanup systems before the reactor is disassembled.

Hydrogen peroxide is also used in the oil and gas exploration industry to oxidize rock matrix in preparation for micro-fossil analysis.

2.3.3 Hydrogen Peroxide Safety

Regulations vary, but low concentrations, such as 3%, are widely available and legal to buy for medical use. Higher concentrations may be considered hazardous and are typically accompanied by a Material Safety Data Sheet (MSDS). In high concentrations, hydrogen peroxide is an aggressive oxidizer and will corrode many materials, including human skin. In the presence of a reducing agent, high concentrations of H_2O_2 will react violently.

High-concentration hydrogen peroxide streams, typically above 40%, should be considered a D001 hazardous waste, due to concentrated hydrogen peroxide's meeting the definition of a DOT oxidizer, if released into the environment. The EPA Reportable Quantity (RQ) for D001 hazardous wastes is 100 pounds, or approximately ten gallons, of concentrated hydrogen peroxide.

Hydrogen peroxide should be stored in a cool, dry, well-ventilated area and away from any flammable or combustible substances. It should be stored in a container composed of non-reactive materials such as stainless steel or glass (other materials including some plastics and aluminium alloys may also be suitable). Because it breaks down quickly when exposed to light, it should be stored in an opaque container, and pharmaceutical formulations typically come in brown bottles that filter out light.

2.4 Potassium Permanganate ($KMnO_4$)

Potassium permanganate is a strong oxidizing agent that can react with hydrogen sulfide in a variety of ways, depending on whether the stream is acidic or alkaline. In acidic conditions, the following reaction takes place:

$$3H_2S + 2KMnO_4 \rightarrow 3S + 2H_2O + 2KOH + 2MnO_2 \quad (2.4.1)$$

Under alkaline conditions the following takes place:

$$3\ H_2S + 8\ KMnO_4 \rightarrow 3K_2SO_4 + 8\ MnO_2 + 2KOH + 2H_2O \quad (2.4.2)$$

Under conditions that are in between acidic and alkaline pHs a variety of reactions occur yielding elemental sulfur, sulfate, thionates, dithionates and manganese sulfide end of the products. Potassium permanganate has been fairly effective when added to the waste production operation.

2.4.1 Disadvantages of Potassium Permanganate ($KMnO_4$)

Dosages are difficult to predict and control in most liquid applications. The high cost and high dose, 6 or 7 parts of potassium permanganate are needed to each part of hydrogen sulfide are discouraging. Safety precautions are required for handling and storage.

2.5 Methane (CH_4)

Methane is a colorless, odorless gas with a wide distribution in nature. It is the principal component of natural gas, a mixture containing about 75% CH_4, 15% ethane (C_2H_6), and 5% other hydrocarbons, such as propane (C_3H_8) and butane (C_4H_{10}). Anaerobic bacterial decomposition of plant and animal matter, such as occurs under water, produces marsh gas, which is also methane.

At room temperature, methane is a gas less dense than air. It melts at –183°C and boils at –164°C. It is not very soluble in water. Methane is combustible, and mixtures of about 5 to 15 percent in air are explosive. Methane is not toxic when inhaled, but it can produce suffocation by reducing the concentration of oxygen inhaled. A trace amount of smelly organic sulfur compounds (*tertiary*-butyl mercaptan, $(CH_3)_3CSH$ and dimethyl sulfide, $CH_3–S–CH_3$) is added to give commercial natural gas a detectable odor. This is done to make gas leaks readily detectible.

Methane is synthesized commercially by the distillation of bituminous coal and by heating a mixture of carbon and hydrogen. It can be produced in the laboratory by heating sodium acetate with sodium hydroxide and by the reaction of aluminum carbide (Al_4C_3) with water.

In the chemical industry, methane is a raw material for the manufacture of methanol (CH_3OH), formaldehyde (CH_2O), nitro methane (CH_3NO_2), chloroform (CH_3Cl), carbon tetrachloride (CCl_4), and some Freon’s (compounds containing carbon and fluorine, and perhaps chlorine and hydrogen). The reactions of methane with chlorine and fluorine are triggered by light. When exposed to bright visible light, mixtures of methane with chlorine or fluorine react explosively.

The principal use of methane is as a fuel. The combustion of methane is highly exothermic.

$$CH_4\,(g) + 2\,O_2\,(g) \longrightarrow CO_2\,(g) + 2\,H_2O\,(l) \quad \Delta H = -891\ kJ \qquad (2.5.1)$$

The energy released by the combustion of methane, in the form of natural gas, is used directly to heat homes and commercial buildings. It is also used in the generation of electric power. During the past decade natural gas accounted for about 1/5 of the total energy consumption worldwide, and about 1/3 in the United States.

Natural gas occurs in reservoirs beneath the surface of the earth. It is often found in conjunction with petroleum deposits. Before it is distributed, natural gas usually undergoes some sort of processing. Usually, the heavier hydrocarbons (propane and butane) are removed and marketed separately. Non-hydrocarbon gases, such as hydrogen sulfide, must also be removed. The cleaned gas is then distributed throughout the country through thousands of miles of pipeline. Local utility companies add an odorant before delivering the gas to their customers.

Some methane is manufactured by the distillation of coal. Coal is a combustible rock formed from the remains of decayed vegetation. It is the only rock containing significant amounts of elemental carbon. The composition of coal varies between 60% and 95% carbon. Coal also contains hydrogen and oxygen, with small concentrations of nitrogen, chlorine, sulfur, and several metals. Coals are classified by the amount of volatile material they contain, that is, by how much of the mass is vaporized when the coal is heated to about 900°C in the absence of air. Coal that contains more than 15% volatile material is called bituminous coal. Substances released from bituminous coal when it is distilled, in addition to methane, include water, carbon dioxide, ammonia, benzene, toluene, naphthalene, and anthracene. In addition, the distillation also yields oils, tars, and sulfur-containing products. The non-volatile component of coal, which remains after distillation, is coke. Coke is almost pure carbon and is an excellent fuel. However, it may contain metals, such as arsenic and lead that can be serious pollutants if the combustion products are released into the atmosphere.